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Data Compression for Deep Space Missions

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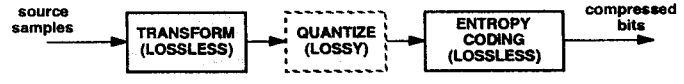
Data Compression Overview

Entropy Coding:

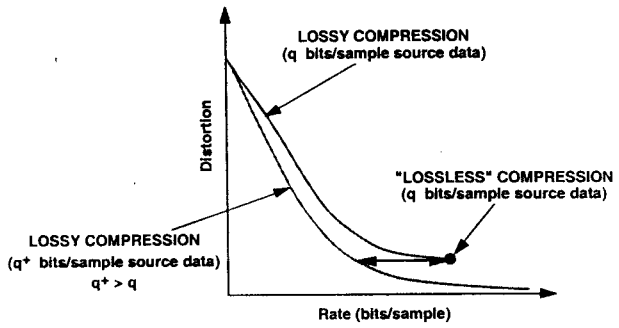
- Examples: Huffman coding, arithmetic coding, Rice coding
- Assign a codeword to each source symbol (or group of source symbols), mapping shorter codewords to more probable symbols

Transform Based Compression:



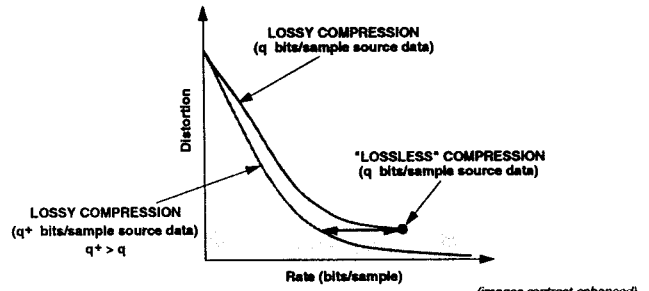
- Transform stage decorrelates data, making compression more efficient
- Transform Examples: DPCM, WHT, ICT, DCT (JPEG), wavelets

Data compression is good (... but don't touch my bits!)



A typical rate-distortion curve

Data compression is good (... but don't touch my bits!)



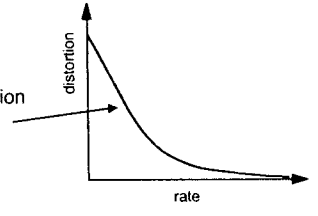
original | "lossless" (q=5 bits) 2.1 bits/pixel | "lossy" (q+=8 bits) 2.1 bits/pixel

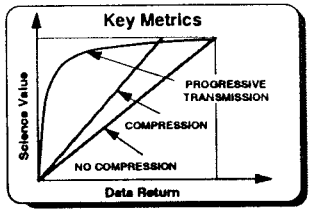
Progressive Wavelet Image Compression: ICER Algorithm

Progressive image compression provides the ability to reconstruct image previews as compressed bits are received. Each new compressed data segment, when combined with previous segments, produces a higher fidelity image.

Goals of ICER image compression:

- Good lossless compression
- Come as close as possible to the rate-distortion limit at each stage in transmission





- Provides advantages in mission planning / buffer management
- To be used on Mars '01 and Mars '03 missions

Progressive Transmission: Raster Scanning

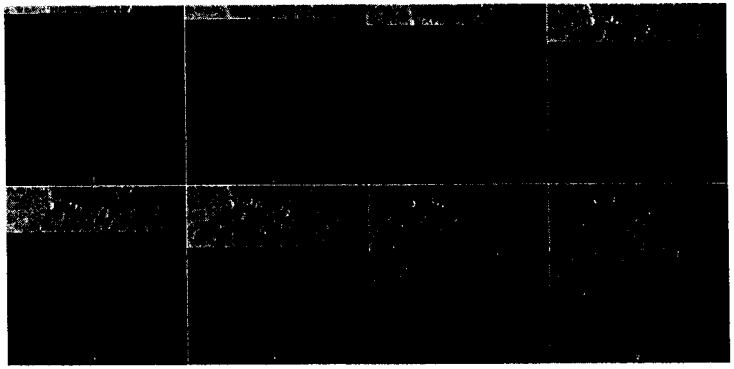
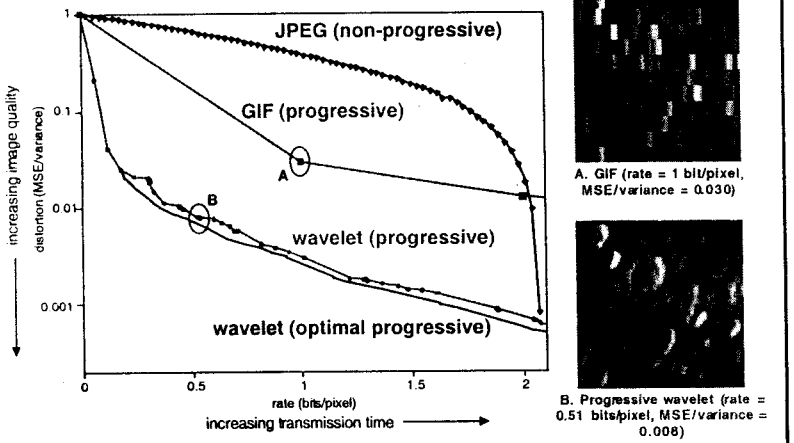


Image sequence under ordinary raster scan image transmission.

Progressive Rate-Distortion Performance

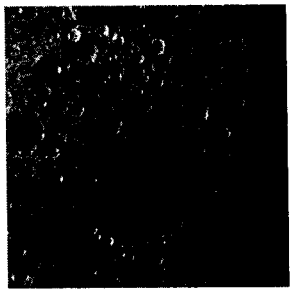


A. GIF (rate = 1 bit/pixel, MSE/variance = 0.030)

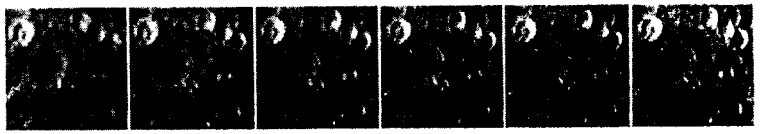
B. Progressive wavelet (rate = 0.51 bits/pixel, MSE/variance = 0.008)

Compression Benefits can be Considerable when Measured in dB

Original Image:



Progressive transmission (detail):

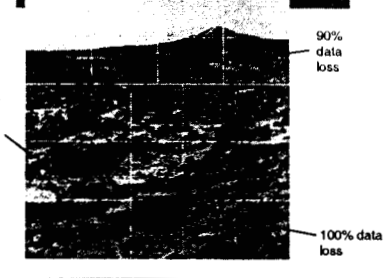


16.5 dB savings | 15.5 dB savings | 13.9 dB savings | 9.0 dB savings | 6.0 dB savings | 2.3 dB savings* (*lossless compression)

Error Containment in Progressive Wavelet Image Compression

The ICER progressive wavelet algorithm incorporates a novel error containment method integrated with packetization.

- **Eliminates blockiness associated with conventional error containment techniques**
- **Arbitrary number of segments can be used to accommodate different channel error probabilities**
- **Supports standard CCSDS packets**

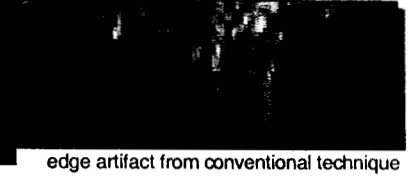


This example simulates three channel errors during transmission of an image divided into 23 segments

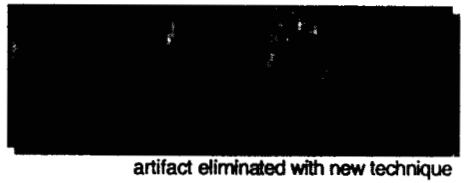
2 bit/pixel image after suffering three CCSDS frame losses due to channel errors

Error Containment in Progressive Wavelet Image Compression

Segmentation for error containment implemented *after* wavelet transform eliminates blockiness associated with the more conventional approach.



edge artifact from conventional technique



artifact eliminated with new technique

Near-Lossless Compression

With small maximum pixel error δ, reconstructed images are virtually indistinguishable from the original when displayed normally.

Artifacts in reconstructed images can be mitigated by using subtractive dither. A range of degrees of dithering is available so one has a choice of how to compromise between:

- Artificial streaks and regions of constant intensity
- An overall grainy look to the image and a slight increase in rate

detail (magnified and contrast-enhanced)
k = dither signal amplitude, δ = 2

original

original

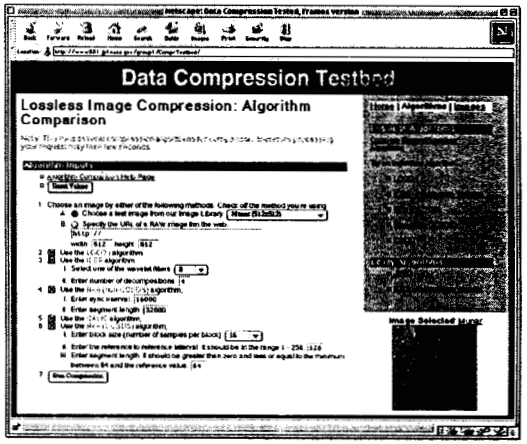
k = 0 (no dither)

k = 1

k = 2 (standard dither)

Data Compression Testbed

The web-accessible data compression testbed allows scientists to observe first-hand the impact of image compression.



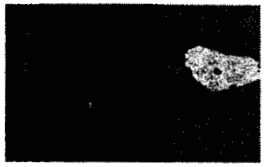
In this example, a user can simultaneously try several lossless compression algorithms on an image.

The Future of Data Compression: On-Board Science Processing

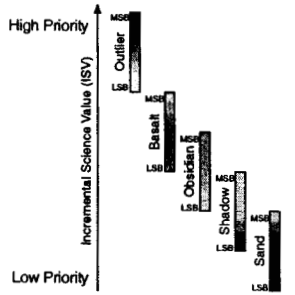
Sam Dolinar, Roberto Manduchi, Adina Matache, Fabrizio Pollara

Missions can always collect more data than can be transmitted. Science classification, progressive compression, and buffer management can work together to selectively transmit the most useful data whenever data collection capability exceeds downlink capability.

original image



output of classification algorithm



priority assignment (example)

Example of On-Board Science Processing

Sample images from Mars Yard

Classification map

Reconstructed images using prioritized buffer manager values based on both *science class value and compression segment value*

Reconstructed images with values based only on *compression segment value* (i.e., keep most important bit planes without regard to science class value)